SIMULATION MODELING OF ADVANCED PILOT TRAINING: THE EFFECTS OF A NEW AIRCRAFT FAMILY OF SYSTEMS

THESIS

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Abstract

This research develops a tool to aid Air Force decision makers in the acquisition of a new trainer aircraft family of systems. The study utilizes discrete event simulation to model the effects a prospective aircraft family of systems has on the flow of student pilots through training processes. Previous research has produced models for student throughput or aircraft availability, this research focuses on the intersection of both. Analysis of results provides insights into the quantity of resources required at the differing levels of performance to sustain a desired throughput of pilot graduates.

I thank God for giving me a wife that could get me through this whole process.

Bryngel J. Erickson

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SIMULATION MODELING OF ADVANCED PILOT TRAINING: THE EFFECTS OF A NEW AIRCRAFT FAMILY OF SYSTEMS

I. Introduction

Background

The United States Air Force maintains a rigorous pilot training program to ensure pilots are prepared to meet future mission requirements. Students preparing to work with fighter or bomber aircraft train with the T-38 Talon during Advanced Pilot Training. The training is a combination of classroom instruction, computer based training, ground based trainer system (GBTS) exercises, and aircraft flying exercises. The intent of the program is to provide students with all the basic skills necessary to transition to their follow-on aircraft.

The T-38 has been an effective training tool in the past; however, it is becoming a less desirable trainer aircraft as time progresses. Originally developed as a lead in trainer for the F-4 Phantom, the T-38 now trains fourth and fifth generation aircraft pilots (Trimble, 2011). The definitions for aircraft generation characteristics vary by industries and nations. In general however, the T-38 and F-4 are third generation aircraft while more advanced systems like the F-15 and F-16 are fourth generation aircraft (Pike, 2012). Development of fifth generation fighters like the F-22 and F-35 has created training requirements that the third generation trainer is unequipped to handle (Trimble, 2011). To compensate for deficiencies in training, the Air Force sends graduates to additional training with F-16 aircraft to bridge the gaps in training prior to a fifth generation fighter assignment.

In addition to technological shortcomings, the T-38 fleet is becoming increasingly more expensive to maintain. The aircraft are old, hailing from a fleet built for the Air Force between 1961 and 1972 (Factsheet, 2005:1). Although each aircraft was designed to last 7,000 flight hours, the average aircraft has flown well over 15,000 flight hours (Trimble, 2011). A combination of metal fatigue, parts availability, corrosion, fuel consumption, and other factors create costs that the Air Force projects to climb significantly in the coming years. In order to avoid these costs and improve the quality of pilot training, the Air Force has decided to pursue a replacement aircraft family of systems (FoS) for the T-38. A family of systems includes not only the aircraft, but all the simulators, computers, and training materials required to conduct pilot training.

Acquisition Approach

One approach to selecting a replacement aircraft FoS is a multistage vetting process that considers both cost and non-cost components as depicted in Figure 1. In the initial phase, the vendor's proposal would be required to meet specific requirements set by the Air Force. Any proposal that fails to meet the baseline requirements disqualifies itself from further consideration. The next phase of competition involves adjusting the total proposed price by considering costs not covered in the initial purchase price. These costs come from a variety of FoS attributes such as aircraft fuel efficiency, additional construction requirements, operation and support requirements, as well as others. Decision makers must choose attributes that are important to them and are quantifiable in dollar figures. After, the adjusted price is calculated, the non-mandatory requirements are compared and scored to give credit to vendor proposals that outperform or penalize

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proposals that underperform in a given criteria. The combination of adjusted price and additional scoring determines which aircraft FoS the U.S. Air Force will select. This thesis will focus on the multivariable price adjustment portion of the procurement strategy.

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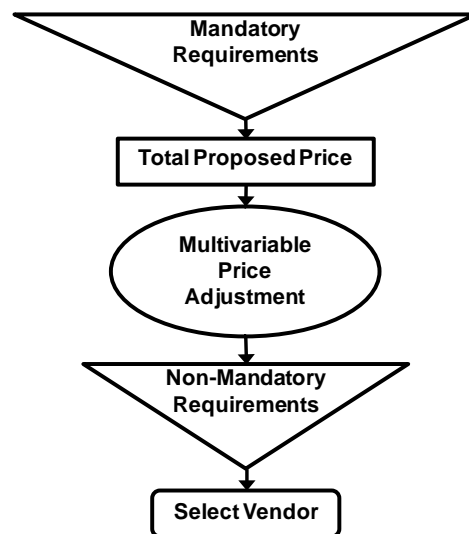
Figure 1. T-X Procurement Strategy

Pilot Training

Air Force pilot training is a multiphase process involving several bases and courses of instruction. Pilot trainees all begin taking the same courses that focus on general aviation principles and skills. Students then separate into specialized tracks in Advanced Pilot Training (APT) for functionally emphasized training such as airlift/tanker, fighter/bomber, turboprop, and helicopter. Following APT, students transition into airframe specific training, such as F-22 or C-17, to prepare for an operational unit assignment.

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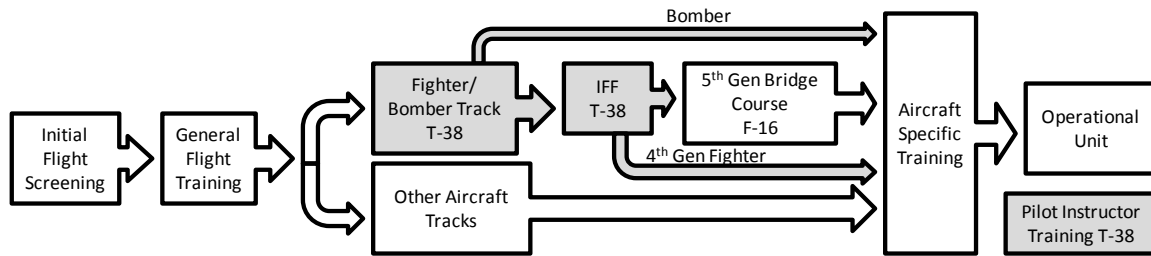
Figure 2. Advanced Pilot Training

The shaded portion of Figure 2 depicts T-38s utilized by the Air Education and Training Command, primarily for the advanced portion of training tailored to future fighter and bomber pilots. The throughput of pilots depends on the skills of individual students, proper timing and delivery of course materials, as well as the availability of resources. There are syllabus optimization studies and sortie generation studies that focus on various aspects of these events. The simulation developed in this thesis will focus on the crossroads of syllabus requirements and aircraft and simulator availability.

Problem Statement

Air Force decision makers need a tool to assist in evaluating costs associated with a proposed aircraft FoS. The tool needs to be able to distinguish between aircraft that perform at different levels of logistics and maintenance capabilities. The tool also needs to provide insight into how future costs may be impacted by a FoS's level of performance.

Research Objectives

This research will deliver a model that uses Arena® based simulation to represent pilot training syllabi. Since the current syllabi do not include lessons for all required

training that the proposed FoS will be able to accomplish, the model architecture will provide a template to support future adjustments in course work. Decision makers will use the model to gain insight on how the proposed aircraft FoS could affect mission accomplishment. In this case, student pilot throughput determines accomplishment of the mission. Using this simulation, decision makers will be able to project how many aircraft and ground based trainer systems will be required to maintain a given level of student throughput. In addition, the model will show the sensitivity of student throughput to variation in FoS performance. The number of aircraft and GBTS needed to produce a desired quantity of students will then be used to adjust the total cost.

Scope

This research uses course flow from the *T-38C Specialized Undergraduate Pilot Training* and *USAF Introduction to Fighter Fundamentals* syllabi to model student progress. No adjustments to course flow are made for optimization purposes. Base and squadron level requirements for aircraft and GBTS form the basis for fleet requirements. The simulation does not factor in depot repair requirements but leaves those adjustments for calculation after the fleet size is determined.

II. Literature Review

Introduction

This chapter describes some of the background knowledge used to develop this study. The chapter outlines benefits of simulation studies as well as the reasons for utilizing Arena® software. Applicable simulation studies are reviewed and simulation models are discussed.

Simulations

Process flows like the ones represented in the pilot training syllabi can be represented in a number ways, to include spreadsheet, simple analytic or mathematical approaches. Although other methods could be used, Carson outlines several good reasons why a simulation approach is preferable for this study (Carson, 2005). When various components interact or function interdependently, the system becomes very complex and difficult to predict the effects of altering one component (Carson, 2005:17). Since pilot training is a combination of multiple moving parts, it is easier to let the simulation play out scenarios than to directly calculate every interaction. Simulation is also preferable when developing a new system or experimenting with new or different demand (Carson, 2005:17). The structure of this simulation not only lets decision makers alter the frequency and size of student pilot classes, it also provides a template for future changes in coursework and their impact on needed resources. Simulations are also desirable when a large financial investment is involved, the system is not fully understood, or considerable risk is present (Carson, 2005:17). Developing a new aircraft is full of high cost risk with future outcomes not usually certain. This model will help

decision makers see the impacts that may occur if they choose an aircraft with performance level x over an aircraft with performance level y. Perhaps the model will show that the impact is negligible and extra money should not be spent on the higher performing system. Another reason for using simulation is for situations where decision makers must agree upon multiple assumptions (Carson, 2005:17). Through this model, the assumptions about the system and their effects can be clearly seen. More importantly, if decision makers do not agree on baseline assumptions, they can easily alter the model and examine the results. The flexibility to change assumptions in the model saves decision makers from having to rebuild a completely new analysis from scratch each time an assumption becomes invalid.

To develop a simulation study, choosing the proper simulation platform is very important. This simulation utilizes Arena® application software to build the syllabi model. Arena® is a practical choice for this research because of accessibility and affordability to the Air Force. Arena® models have been used extensively in the past so operating license access and familiarity with the program will not be a large obstacle for decision makers. The software is also a simple-to-use graphical module interface that lets novice programmers quickly understand and manipulate complex logical structures. The graphical modules are ideal for processes flow analysis because they allow reviewers to see how entities move and interact through the model. The overall effectiveness and simplicity of Arena® make the software an ideal choice.

Previous Studies

Several studies have looked at resource constraints on pilot training programs. Although the focus was different in each study, two previous research projects were particularly applicable to this thesis project.

First Lieutenant Okal developed an AFIT study in 2008 that looked at the training process of fighter pilots in the Turkish Air Force. The study analyzed one course of instruction broken into multiphase successive modules. Okal developed an Arena® based simulation model to analyze affects on total training time that would occur with varying levels of resource availability. As the number of instructor pilots, student pilots, and aircraft changed, the model calculated the total time required for a student to complete the required training (Okal, 2008). Analysis of the model provided decision makers with insight into how many of which resources would be required to support future student class sizes (Okal, 2008:67-70). A limitation of Okal's study was the lack of maintenance and logistics variability. Once set, the number or aircraft available for student use did not vary so the effect of maintenance delays was lost in the system.

Raivio et al. developed an Arena® based simulation that modeled the use of the Bae Hawk Mk51 aircraft. In this model, the Finnish Air Force's pilot training program forms the framework of daily operations (Raivio et al., 2001:190). The model uses daily training sorties to calculate aircraft flying hours as a metric for maintenance requirements. After each aircraft lands, the model assess probability of breaks based on historical data to determine one of three levels of possible maintenance. The model is able to use very specific distributions for each level of maintenance repair time due to an abundance of statistical data. From the detailed simulation of break and fix rates, the

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simulation team developed a four year projection of daily aircraft availability rates. The

team was also able to show how the rates would change if manpower capability was

scaled up or down (Raivio et al., 2001:194).

LCOM

The Logistics Composite Model (LCOM) was designed by the Air Force and The

Rand Corporation in the 1960s as a sortie generation analysis tool (Boyle, 1990). Figure

3 below shows a very basic format of the LCOM functionality.
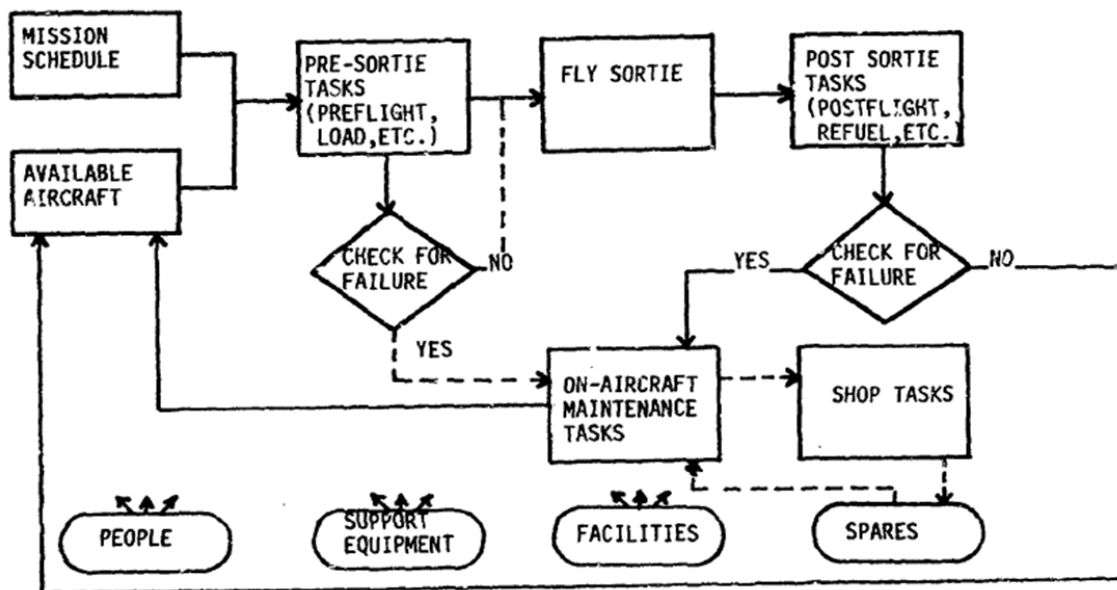
Figure 3. How LCOM Simulation Works (Richards, 1983:4)

In the LCOM model, aircraft are the flow-units that process through the model.

The simulation moves the aircraft through phases of preflight, flying, and post flight

activities to simulate the work of a maintenance organization (Boyle, 1990). The model's

modules pull resources required for task completion and hold them for the specified

required time to complete the task. If there are not enough resources for a specific

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operation, the aircraft waits until resources are available. If too many backlogs occur, flying missions are canceled to reduce the demand on aircraft. The user inputs information about the number of available resources to pull from. The user also defines how long events are expected to take and what their statistical distributions look like. By adjusting the levels of resources and altering the performance of aircraft, a decision maker can get a better idea of what he/she will need to support a certain level of aircraft activity.   Decision makers can use the tool for a variety of applications but the focus is to determine appropriate levels of resources, including manpower, to meet a flying demand (Boyle, 1990).

One of the downsides of the LCOM model is it is very large and complicated to handle. Significant time is required to prepare input data to feed into LCOM and additional time is required to make sense of over 200 output statistics generated (ACC, 2013). In order to be able to use the tool effectively, the user would require several months of full time study and the aid of technical support (ACC, 2013).

SIMFORCE

The Scalable Integration Model for Objective Resource Capability Evaluations (SIMFORCE) is a simulation model developed under the Air Force Research Lab as a simple tool to provide logisticians an ability to measure the effects of logistics constraints on operational capabilities (Brown and Powers, 2000:1050). SIMFORCE aims to reduce wing level analysis gained from programs like LCOM down to a unit level while also including more detailed information about the types of resources required (Brown and Powers, 2000:1050). The format of this model allows unit level decision makers to

conduct desktop analysis without the need for a large database or technical support. The program quickly shows the impact on sortie generation if assets become unavailable.

Another feature of SIMFORCE is inputs are accepted and outputs generated without the user having to look at any of the process (Brown and Powers, 2000:1050). The black box approach lets users interface with simple graphical interface queues and excel forms and does not require them to have skills in programming. Not only does the layered approach simplify functions for the user, it can also shield the program from view so that logic is not accidently altered or purposefully gamed.

Summary

The research and programs cited in this chapter show that aircraft generation and student flow studies can be approach from a variety of ways. An Arena® simulation will provide simple to understand analysis capabilities that can be delivered to decision makers in a number of different formats. An open program may be best for some decision makers while a black box approach may be better for others.

The model developed for this study will not simply focus on student flying tasks or daily sortie generation capabilities. This model will be a synthesis of past work that shows how student progress is affected by the varying availability of GBTS and aircraft at different times of the day.

III. Methodology

Chapter Overview

The model developed for this study is designed to simulate how the number of aircraft and ground based trainer systems (GBTS), as well as their level of performance, affects the flow of students through pilot training. To measure the training program's effectiveness, the simulation reports the number of students that complete the training as well as the number of students that are delayed throughout the training due to a lack of available resources. The user adjusts the quantity of aircraft and GBTS to identify the minimum number of aircraft and GBTS required for consistent student throughput. In addition, the user adjusts aircraft and GBTS performance levels to affect the availability of these resources to support student flow through the model. This chapter outlines the functionality of the model starting from a course view and narrowing down to a daily process and event focused perspective.

Assumptions and Limitations

The statistician George Box noted, "All models are wrong, but some are useful." The model in this study is no exception to Box's remark. Multiple assumptions and limitations reside in this study in order to create a product that can provide insights to decision makers even though the model does not exactly replicate reality.

- The performance level of the resources assume that 20,000 fleet hours have already occurred. The model does not reduce resource performance as flying hours increase.

- The model excludes federal holidays and Christmas break from the training year to better capture class overlap durations. The training year consists of 343 training days and weekends.

- Each class will have the same number of training days to complete the respective tracks. The interval between class start dates is determined by the interval between scheduled graduation dates.

- Students progress through the model as outlined by the syllabi. The model segments the training days into five training day weeks separated by weekends. Within a week, a student cannot progress more than one day ahead of schedule. Delays due to no available resources may be made up within the week. If the student does not catch up by the weekend, the model holds them back a week.

- Students must wait for resources to become available to progress to the next task. Tabletop or lecture based workarounds used in real life are not used in the model.

- The model duplicates a certain percentage of each class to simulate additional training requirements. These additional students represent constraints on resources due to non-progression, ineffective sorties, unaccomplished tasks, etc. The model does not count these duplicates when calculating delayed students or graduation statistics.

- A student is limited to 12 hours a day to complete aircraft training and 8 hours for GBTS training.

- Delays due to weather and sickness or emergencies will not be simulated. It is assumed that the syllabi have sufficient flex days built in to compensate and weekends would be used if necessary to maintain scheduled graduation dates.

- The number of available computers, instructors, classrooms and airfield resources are not constraining factors. However, classroom instruction must be completed within the 12-hour flying day.

- All students will complete the entire training program without dropping out or recycling back to a later class.

- Current syllabi do not integrate fifth generation requirements or capabilities throughout the course. This model is developed in anticipation of updated syllabi and will serve as a framework for adjustments.

- The model structure must remain simple, easy to understand and edit, and only focus on a small number of decision variables.

With these assumptions and limitations, the methodology still captures the main effects that affect aircraft and GBTS resource availability and effectiveness during pilot training.

Course Flow

The simulation uses syllabi for two courses, Introduction to Fighter Fundamentals (IFF) and T-38C Specialized Undergraduate Pilot Training (SUPT), as the framework for course completion. The simulation creates students as a class and pushes each class of

students through the training together. Within each syllabus are several track options that a student can take. The model assigns an identifier to each student for the track of instruction the student will follow as well as an identifier for when the student started training. After the model assigns tracks, the students flow through each week of instruction until the course is complete. After completion of instruction for a syllabus, the model records how many students have graduated. If there are not sufficient resources to graduate each student on time, the model records how many students graduated one, two, three, four or more weeks late. In addition to the daily training processes, the model includes processes to reduce the number of available resources resulting from maintenance requirements.

A Week's Schedule

The depiction in Figure 4 is a partial representation of a training week. Figure 4 features two training days with a variety of aircraft tasks, a GBTS task, an academic task, as well as logic used to manage the movement of students along syllabus tracks.
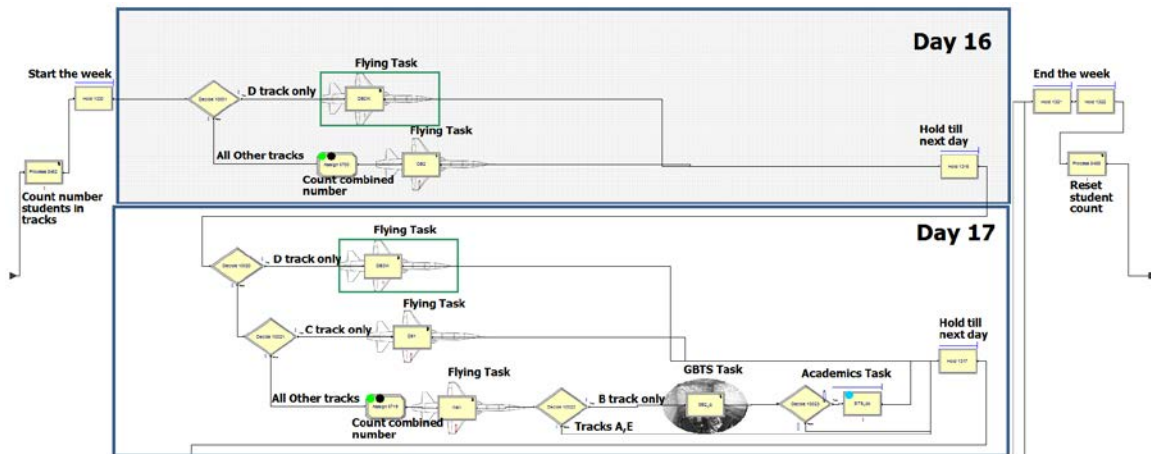

Figure 4. A Simulation Week

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For each training week, the model begins by counting the number of students that will process through that week's activities and the number of students in each track. The model holds students until the model timer reaches the beginning of the week. After the model's clock reaches the start of the first day of the week, students flow through their respective tracks and complete the necessary academic, aircraft, or GBTS training. Once the students finish the first day's tasks, the students again hold until the clock marks the beginning of the next day. If the new day has already begun and the student is still completing tasks from previous days due to a lack of available aircraft or GBTS, the model will immediately flow the student to the next day. If a student does not process through each day before the weekend arrives, the model holds that student in the current week while the rest of the class flows to the next week. In order to allow the last training day of each week to have flexibility like the previous days, students may flow immediately from the fourth day to the fifth without delay. The flexibility between modeled days simulates the flexibility instructors have to adjust scheduled activities during the week to meet syllabus priorities and avoid bottlenecks caused by rigid syllabus schedules. After the end of the week, the model resets all the variables used for counting students in preparation for the next class. After the model completes the week, it pushes the students on to the next week's activities.

Scheduled Maintenance

Aircraft scheduled maintenance is a periodic process used to proactively avoid problems and ensure the aircraft is in working order. Specific aircraft components require various maintenance schedules since not all components are as robust as others

are. Intervals between scheduled maintenance actions can be based on a number of factors such as number of uses, hours of use, fly hours flown, days since last inspection and so forth. For the purpose of this study, the number of flying hours since the last scheduled maintenance event defines the interval time between scheduled maintenance. The user inputs a value into the variable *AcftTimeBetweenScheduleMx* to set how many flying hours the model counts before schedule maintenance on an aircraft occurs.

The user defines the amount of time an aircraft may spend in scheduled maintenance based on a triangular distribution. The user inputs the time-to-fix into the variables *AcftScheduleMxTimeLow, AcftScheduleMxTimeAvg,* and *AcftScheduleMxTimeHigh*. These times represent the total time an aircraft is not available to fly because of actions associated with scheduled maintenance. This stipulation assumes the user factors in maintenance delays and logistics delays into the fix-time. A triangular distribution is appropriate for this model because prospective aircraft may not have sufficient data to establish a known distribution (Banks et al., 2010:183). The triangular distribution is also beneficial because it can bound known minimum and maximum durations while still allowing the flexibility to include a tail for unexpected delays. For the purpose of scenarios analysis, this study sets the low, average, and high values of scheduled maintenance equal to each other since appropriate distribution data was not available. Unscheduled maintenance actions will be explained later in the thesis.

GBTS Maintenance

Maintenance actions for the ground based training systems are not based on a scheduled or unscheduled maintenance action like aircraft maintenance. This study assumes that all of the GBTSs are stationary flight simulators and system failures will resemble those of a network of computers. Computer failures are represented as rates that measure the number of failures in a given sample size over a specified period of time (Schroeder and Gibson, 2007:1). As such, it is appropriate to represent GBTS failure rates and variable fix times with the overall mission capable rate of the system rather than on some level-of-use metric.

The decision maker provides the mission capable rate of the GBTS as the percent of time a system is available for use, represented by the variable *SimAo*. The simulation randomly selects each GBTS each day and holds the asset for a portion of the day not included in *SimAo*. As an example, to represent maintenance requirements the model would randomly pull a GBTS and hold it for 20 percent of the day if the GBTS mission capable rate was 80 percent.

Academic Instruction

Pilot training divides academic instruction between instructor based class instructions, ground training and computer based instruction. The focus of the research is on GBTS and aircraft requirements, so resources associated with academic training are not constrained. Although academic resources are not a factor, the time required to complete academic training constrains the student with fewer available hours to complete GBTS and aircraft training. As a result, the model treats academics as a simple delay in

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order to model the constraint on available time to complete other activities. The model

holds each student for the duration of the class time before moving the student on to the

next task.

Aircraft Training

The simulation models aircraft training events with a submodel consisting of three

major functions, batching, training time and aircraft maintenance. Figure 5 depicts the

three functions with how they work detailed below. Figure 5 is the most robust version

of aircraft simulation logic and can handle up to four student pilots with any number of

aircraft. For training tasks that require less than four students, the model uses simplified

versions of Figure 5 that require less coding for the batching and maintenance portions of

the submodel.

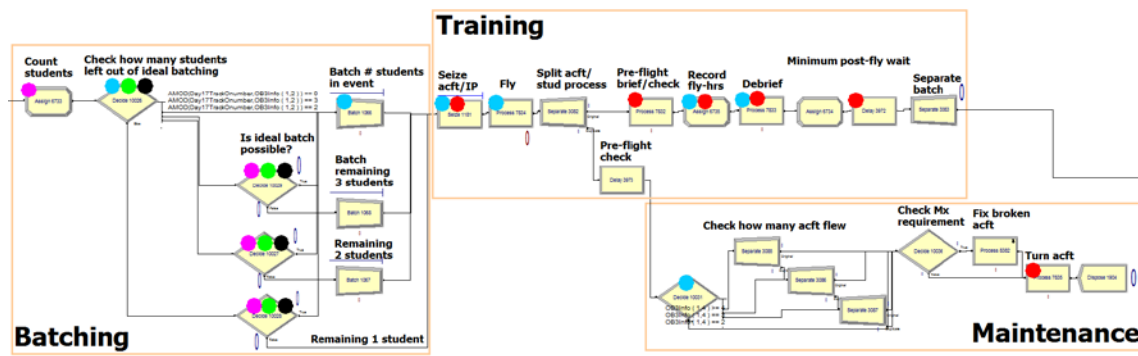Figure 5. Aircraft Training Event

Aircraft Training-Batching

The purpose of batching is to simulate aircraft training events that require

multiple students to train together. The batching process compares the number of

students that will pass through the event that day with the number of students the event

requires to train together. The model will count out the students as they arrive and

combine them into a single batch, sized by the user's input. If there are not enough students to fill an entire batch, the remaining students form a smaller partial batch.

Aircraft Training-Training Time

After a group of students is batched, the batched students complete the training together. If the required aircraft are not available, the group of students will wait until enough resources become available to complete the training. Normally the students would conduct a mission brief, preflight check, fly the training mission, debrief and then continue to the next training event for that day. The top half of Figure 6 reflects this order.

In order to capture the unique processes of aircraft and students, the model sequences events to follow the path in the bottom half of Figure 6. The model seizes aircraft and instructors at the same time and simulates flying the training mission. From this point, the model splits the processes into student and aircraft specific tasks. Students experience time delays to simulate mission briefs as well as debriefs. The mission brief delay begins at a specified amount of time prior to flight takeoff and encompasses a delay for preflight checks. At the end of the training time, the model delays the student for the required time a student must wait post-flying before starting another training event. Aircraft experience time delays to simulate preflight checks and maintenance actions.
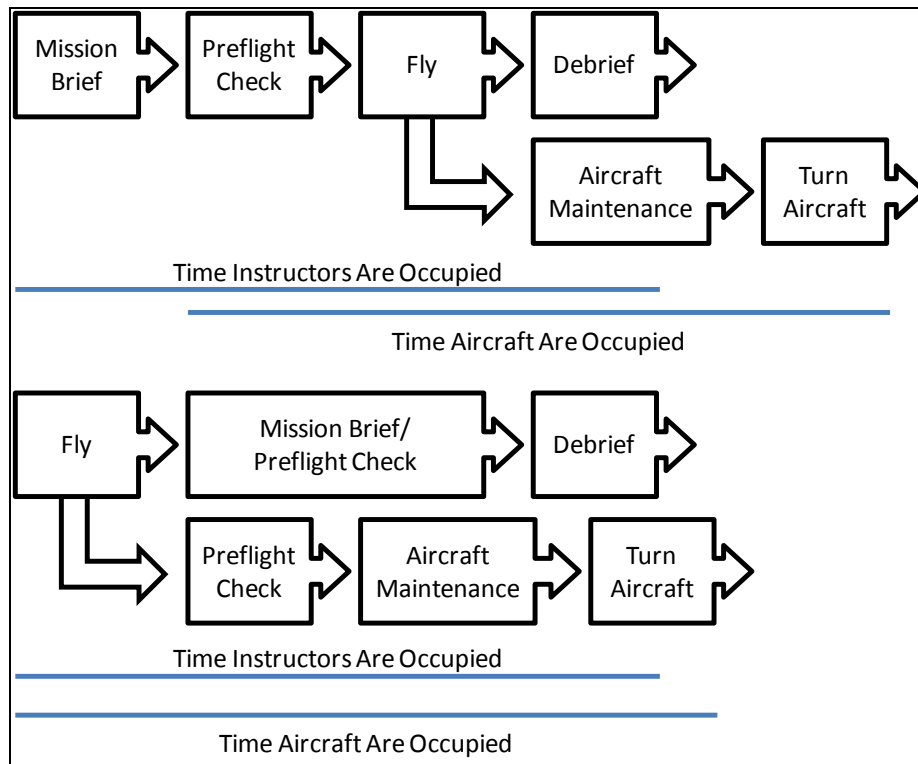
Figure 6. Aircraft Training Process

By using this modified sequence, the model can link student and resource requirements in a less complex format while maintaining fidelity. This format maintains the time intervals between successive events for both students and aircraft. This format also synchronizes the resources in a way that is flexible enough for the user to add constraints on instructor pilot availability in future research. Specifically, this format avoids situations where students seize instructors for the mission brief and then hold them for several hours while waiting for aircraft to become available.

Aircraft Training-Aircraft Maintenance

Following a training mission, maintenance personnel check the aircraft to ensure proper functionality. If the aircraft lands with inoperable mission-essential systems, it

becomes "Code-3" and requires unscheduled maintenance (AFPAM 63-128, 2009:157).

Code-3 conditions also include ground aborts (AFPAM 63-128, 2009:157).   Once the

inoperable system is fixed, the aircraft is prepared for the next training mission.

The model determines which aircraft need unscheduled maintenance based on a break

rate percentage. The variable *AcftBreakRate* is calculated as the percentage of Code 3

breaks per training sorties flown. After aircraft complete the training mission, the model

probabilistically selects which ones will require maintenance. The duration of time an

aircraft spends in maintenance depends on an eight-hour fix rate with a gamma

distribution. The eight-hour fix rate represents the percentage of aircraft that land Code-3

and can be fixed within eight-hours. The fix rate is an appropriate metric because it is a

maintainability measure that combines logistics and administrative delays with the direct

maintenance time (AFPAM 63-128, 2009:158). This rate, and an estimated shape

parameter, act as inputs to an excel solver function to generate the scale parameter of the

gamma distribution as well as the mean fix time. The gamma distribution is an adequate

application for simulating machine repair-time variability (Law, 2007:285). The model

delays the aircraft resource for the duration of time determined by the gamma

distribution.

A series of logic blocks determine when the aircraft began maintenance, ended

maintenance, and if any of the time in between spanned maintenance off hours or

weekends.   If any of the delay time coincides with weekends or maintenance off hours,

the model adds this time to the original delay. The reason the model utilizes test logic

instead of resource schedules is because of Arena® functionality errors. Normally a

schedule with preempt delays would sufficiently add down time to the required fix time

in the event the fix time spanned a weekend or maintenance off hours. Verification

testing identified a glitch in this functionality, however, and forced the utilization of

cascading logic functions as a workaround. During verification tests, the preempt feature

only operated as advertised when the model had fewer than three students to process.

With more than three students however, maintenance actions continued to process instead

of delaying the fix until maintenance resources again became available.

After the appropriate amount of time, the model releases the aircraft from

maintenance work, or bypasses the process if no breaks occur. Following corrective

maintenance actions, the aircraft begins preparation for the next mission. The mission

preparation delay is the average time required to turn the jet. This average time is

defined by the user set variable *AcftTurntime*.

Weapon Systems Operators

Most aircraft training events follow the same structure mentioned above with

batching, training time, and maintenance elements. The exceptions to this format are

aircraft training events designed for weapon systems operator (WSO) students. For

dedicated training events, the WSO student has his/her own jet. In these cases, the event

follows the format outlined above. In non-dedicated training events, the WSO flies in the

back seat of the aircraft while another student pilot conducts aircraft training.

The training syllabus maps WSO students on their own track, even though the

WSO student is dependent on the other tracks to complete training (AETC, 2013: 62).

As a result, the syllabus course flow may not be possible to follow if the other tracks do

not have sufficient student pilots on a given track. In the real world, the WSO track

schedule synchronizes with the other tracks in a given class so that flying tasks match up on the same days. After synchronization, the non-dedicated WSO training does not constrain any resources beyond what the student pilots are already using. To capture this effect, the model treats non-dedicated WSO events as simple delays that do not seize any resources. Instead, the WSO student holds for amount of time to cover the brief and flight check, flying training, debrief, and minimum student wait time. With this process, the model still tracks the number of resources required and the number of hours left in the day to complete other training events.

GBTS Training

Training with ground based trainer systems follows the same basic flow as training with an aircraft. The student has a prebrief with the instructor, flies the training mission, debriefs and moves on to the next task. The model structure to simulate GBTS training is only slightly different from the structure for aircraft training.

The batching logic in the GBTS submodel is identical to the batching logic in the aircraft submodel explained above. Although most GBTS events are only single student events, the model is scalable to accommodate multiple students training together on linked systems. Unlike the maintenance portion of the aircraft submodel, the GBTS maintenance portion does not include a process for unscheduled maintenance. The GBTS Maintenance section of this thesis explains how the model simulates scheduled and unscheduled maintenance requirements. The maintenance section of the submodel does however include the necessary delay to set up the GBTS for the next training

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scenario. The training time portion of the submodel is also similar to the aircraft

submodel's training time except there is no extra delay included for preflight checks.

Additional Training Requirements

Pilot training involves many difficult tasks that very few people master the first

time. Whether the student is not learning the material quickly enough, or the aircraft is

not functioning properly, additional sorties are often required to complete training. To

capture the strain on resources that additional sorties create, the model creates a number

of shadow students to process with each class. The user determines what percent of

aircraft or GBTS sorties require repetition. If a class of ten students can pass a scheduled

lesson with one sortie each, then no shadow students are required. If the class requires an

additional three sorties for training or to make up for maintenance problems, however,

the model would need three shadow students to perform the additional sorties. For the

purposes of this study, the model uses a ten percent additional sortie requirement based

on planning factors stated in the syllabus (AETC, 2013:3). After the model generates

entities to represent each student it assigns the students to specific tracks of instruction.

After students are in their tracks, the model replicates ten percent of them and assigns an

attribute to the replicated entities to identify them as shadow students. These shadow

students create the additional requirements for aircraft and GBTS but the model does not

include them when calculating statistics for student throughput.

IV. Analysis and Results

Verification and Validation

Prior to conducting tests and analysis, model verification ensures that the model functions as the user would expect. This study utilized several verification techniques to build confidence in the model's ability to guide insight. In order to avoid the occurrence of typographical errors in the logic throughout the model, variable names pulled from dropdown menus were used extensively. When replicating submodels, the previous submodel provided the framework for the following submodel. This copy-and-paste process forced the model builder to inspect each process for correctness prior to updating the information for the following submodel. In addition to inspection of each module's logic, visual analysis of process flows ensured that entities flowed through the model appropriately. Through use of the animation function in Arena®, each type of submodel was inspected prior to inclusion with the rest of the model. The use of test scenarios combined with the statistical data produced by Arena® output reports, further validated that model logic functioned as intended.

Along with verification, validation ensures the model will provide usable information to decision makers. While verification ensures the model is running properly, validation ensures the model sufficiently represents the real system (Carson, 2002:52). Input from subject matter experts guided the development of the model's weekly training processes as well as the training submodel structures. Discussions with maintenance professionals and pilot instructors ensured that the model included applicable elements of the real world. In addition to input from subject matter experts,

pilot training syllabi and data from the Air Force Training Information Management

System provided input for process times, resource schedules, and activity delays used

throughout the model. Further validation of the model occurred through a comparison of

model outputs generated by the Arena® process analyzer tool. Table 1 below compares

real world data for annual sortie generation and flying hours with model outputs. The

statistics for current data reflect the minimum fly hours and sorties generated for an

average of 100 students in a year. When no extra shadow students are included, the

model outputs the second line of statistics in Table 1. This data reflects the minimum

flying hours and sorties required when no less than 100 students are expected to graduate

and absolutely no additional sorties are required. Line three shows the surge capacity

statistics for worst-case scenario planning. This study evaluates the worst-case scenario

with the assumption that the Air Force will want to maintain current surge capabilities.

Table 1. Annual Fly Hours and Sorties (Factsheet, 2012)

	# Annual Fly Hours	# Annual Sorties
Current	>13,000	>11,500
Model w/o 10% increase	13,391-13,399*	11,284-11,276*
Model w/ 10% increase	14,583-14806*	12,280-12,467*
*95% confidence intervals		

Replication Parameters

The scenarios in this study analyze both stochastic and non-stochastic elements of

the pilot training process. Aircraft break rate, 8-hr fix rate, non-scheduled aircraft

maintenance time, additional training requirements, student training tracks and GBTS

availability all add randomness to the model. Other elements such as scheduled

maintenance time, aircraft and GBTS turn times, training times, briefing times, and class sizes are assumed constant in this model. In order to obtain meaningful information from both stochastic and nonstochastic elements, the scenarios in this study follow specific replication parameters.

The model uses a one-year warm up period and a year long run time to produce scenario results. Six months are required to populate the SUPT training curriculum with students in training stages from start to finish. Until the entire course initializes, the resources are not fully constrained. Another six months are required to fully constrain the resources as they currently are in the real world. After a year of initialization, entities have both filled the entire model and produced the appropriate constraints on resources. A year's worth of students then process through the model to measure the effects of course requirements and resource availability on student throughput.

The model runs each scenario fifty times to generate the appropriate data in analysis. By increasing the number of replications, confidence intervals decrease to allow better representation of data. Confidence interval half-length analysis, determines the appropriate number of replications required to reach a desired confidence interval span (Banks et al., 2010:431). Some parameters in this study can be determined with 10 or 20 replications, however MTBM requires fifty replications to gain accuracy within $\pm.1$ maintenance actions/fly hours at the 0.05 significance level. Fifty replications also produce confidence intervals within ±139 and ±117, at the 0.05 significance level, for number of annual aircraft flying hours and number of annual aircraft sorties respectively. With these replications, the average number of aircraft sorties per scheduled aircraft per day is accurate to within ±0.03 sorties with a 95% confidence interval.

Baseline Single Base SUPT Scenario

Analysis began with a baseline scenario that used the resources available at a

representative base. Laughlin AFB and its associated SUPT curriculum served as the

baseline scenario. A total of 65 aircraft and 7 GBTS with a student throughput of 103

students per year characterize the scenario environment. In order to maintain surge

capacity, evaluations focused on supporting 120 students rather than 103. The model

utilizes the threshold values stated in the T-X presolicitation documents to initialize

variables for aircraft and GBTS performance factors. The minimal performance factors

and system attributes used in the model are listed on FedBizOpps.gov and displayed in

Table 2 below (Christian, 2013). The baseline includes an additional ten percent shadow

student increase to each class to simulate refly requirements that can be expected to occur

(AETC, 2013:3). These threshold attributes represent the current capability of the T-38

family of systems and the minimum level of performance that the Air Force requires the

T-X FoS to meet (Christian, 2013).

Table 2. Draft Key Performance Factors and Key System Attributes (Christian, 2013)

Attribute	Description	Threshold
GBTS-Ao	Percentage of time GBTS are operationally capable of performing mission	No less than 80%
Aircraft-Ao	Percentage of time aircraft are operationally capable of performing mission	No less than 64.7%
Aircraft Turn-Around Time	Mean time it takes to recover an aircraft and complete any preparation needed to ready the aircraft for the next mission	No greater than 0.75 hours
Aircraft Break Rate	Percentage of aircraft that land Code-3	No greater than 8%
Aircraft Fix Rate	Percentage of Aircraft that land Code-3 and can be fixed within 8 hours	No less than 75%
Aircraft MTBM	Mean time between corrective and preventative maintenance actions	No less than 14.71 flying hours

In order to evaluate whether or not the scenario can support the required annual student graduation rate, an analysis of model output data is required. The Arena® process analyzer tool allows the user to manipulate a vast array of model inputs and generates many output statistics. With the simulation-produced statistics, the study uses Excel spreadsheets to produce additional statistics for MTBM, # sorties per resource, and aircraft availability. Figure 7 below highlights some of the statistics of interest for this study as well as the results of the analysis process with baseline scenario inputs. Although the number of aircraft and GBTS function as inputs for the simulation model, the number of resources required to support 120 student graduates annually are an output generated by the analysis process.
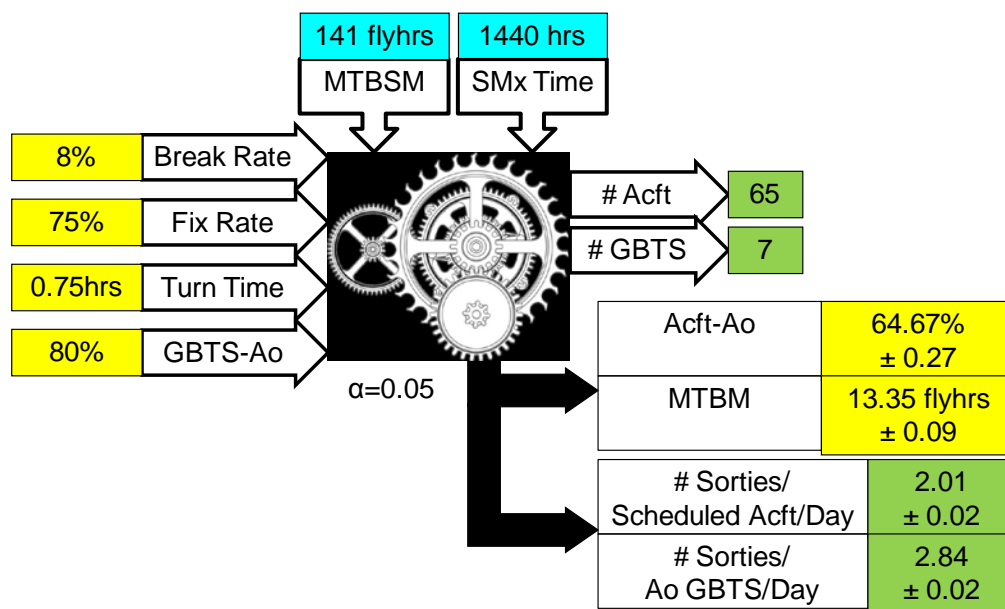

Figure 7. Baseline Scenario w/120 Graduates

The data in Figure 7 highlights that the model was able to graduate 120 students on time. When determining the appropriate number of aircraft and GBTS required to support pilot training, this study will only accept scenarios where all of the students are

able to graduate on time. Maintaining one hundred percent on time graduation not only holds true to the baseline capability, it also avoids the issue of deciding how many delayed students are too many.

Aircraft availability is a function of aircraft maintenance times and frequency of scheduled or unscheduled maintenance actions as a result fleet flying hours. It is important to note that aircraft availability is an output statistic dependent on flying hours and maintenance actions. Scenarios with different number of aircraft or different number of flying hours will have different availability rates even though the maintenance requirements are the same. In early stages of this study, the model employed aircraft availability rates as an input, much like the GBTS. This format skewed the data and gave the impression that far fewer aircraft than were actually necessary could support pilot training requirements. When developing scenarios, this study uses the threshold attributes to establish the aircraft availability at the most stringent point before relaxing constraints.

The model outputs utilization rates for both aircraft and GBTS. These rates are a combination of training use as well as maintenance use. These statistics are important tools that help decision makers understand not only how many resources are required to complete the mission, but also how busy those resources are on a daily basis. Equation 1 below outlines how data taken from the process analyzer was manipulated to obtain number of daily sorties each aircraft on the flying schedule would have to fly in order to meet demand requirements. This study assumes that of the unit assigned aircraft that are mission capable, 75 percent will be available for use on a given day. In accordance with

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maintenance practices, the other 25 percent are held in reserve to ensure enough mission

capable aircraft are ready the following day.

$$S = \frac{(Ua - 1 + Ao) \cdot A \cdot 24 \cdot 7}{(T + F + C) \cdot 5 \cdot A \cdot Ao \cdot Sc} \qquad (1)$$

Where:

S = Average number of sorties per day per scheduled aircraft
Ua = Total aircraft utilization
Ao = Percentage of time aircraft are operationally capable of performing mission
A = Number of aircraft assigned
T = Aircraft turn time
F = Average sortie duration
C = Flight check time
Sc = Percent of mission capable aircraft placed on the flying schedule

With data generated by the baseline scenario of the model, the above equation

shows that 31 scheduled aircraft would fly an average of 2.01 sorties each day to support

the surge student throughput.

The metric for mean time between maintenance (MTBM) proved to be

problematic for this study. At the threshold performance levels, the baseline scenario

was not able to meet the minimum requirement of no fewer than 14.71 flying hours

between maintenance actions. Even when excluding scheduled maintenance actions, the

model could barely meet MTBM threshold levels when the aircraft break rate was at

threshold levels. In order to satisfy the threshold requirement at the objective level break

rate, the average time between scheduled maintenance would have to exceed 230 flying

hours. At this interval, each scheduled maintenance action would average in excess of 90

days. Most scheduled maintenance actions on the T-38 are minor periodic inspections

that range from a week to a month in duration (Maysonet, 2013). More extensive and

less frequent inspections last for 45 days (Maysonet, 2013). The fact that the model would require an aircraft to receive scheduled maintenance less than twice a year for over 90 days suggests that the MTBM metric or the aircraft break rate or the aircraft fix rate metric may not reflect real world values.

Future State Scenarios

With the background information gained from the baseline test, decision makers are able to test possible future scenarios. A comparison of both results shows the impact of future changes on the current state of operations. Currently the Air Force is considering purchasing 350 T-X aircraft to replace the aging T-38 fleet. Although the new aircraft will be easier to maintain, the new fleet would still constitute more than an eighteen percent reduction in available aircraft. The future state scenarios in this study begin with 53 aircraft instead of the current 65 to represent the proportional reduction in the fleet. Tables three through five below show the results of possible future state scenarios. Each table shows the effects of shifting FoS attributes from threshold levels to objective levels while maintaining the same scheduled maintenance plan as well as the same number of aircraft and GBTS. Between the three tables, the scheduled maintenance plan adjusts the aircraft availability.

Table 3. Attribute Trade Space with 64.7% Mission Capable Minimum

53 Acft, 7 GBTS, 141 MTBSM, 1163 SMx Time							
Input				Results			
Break Rate	Fix Rate	Turn Time	GBTS -Ao	% Acft-Ao	MTBM	# Sorties/ Scheduled Acft/ Day	# Sorties/ Ao GBTS/ Day
T	T	T	T	64.68	13.42	2.46	2.83
T	T	T	O	64.52	13.43	2.47	2.53
T	T	O	T	64.72	13.39	2.46	2.83
T	T	O	O	64.87	13.45	2.45	2.51
T	O	T	T	64.78	13.37	2.47	2.84
T	O	O	T	64.93	13.36	2.46	2.83
T	O	T	O	65.03	13.43	2.45	2.51
T	O	O	O	64.89	13.39	2.47	2.52
O	T	T	T	64.96	15.12	2.45	2.84
O	T	T	O	64.77	15.20	2.47	2.54
O	T	O	T	64.83	15.16	2.48	2.85
O	T	O	O	64.87	15.14	2.47	2.53
O	O	T	T	65.02	15.11	2.46	2.83
O	O	T	O	64.99	15.12	2.47	2.53
O	O	O	T	65.1	15.15	2.46	2.83
O	O	O	O	65.04	15.08	2.47	2.52
95% Confidence Intervals				±0.3	±0.11	±0.03	±0.02
T= Threshold, O= Objective, MTBSM=Mean Time Between Scheduled Maintenance SMx Time= Mean Scheduled Mx Time							

The data in Table 3 shows that even with an eighteen percent reduction in aircraft, the base fleet would still be able to support pilot training requirements at a surge capacity. The very small variability in response factors also indicates that fluctuations between threshold and objective levels of performance factors have no significant impact on how many resources are required to accomplish training requirements. The largest variability resides in the MTBM statistics, which still show that threshold levels of break rates do not meet threshold requirements for MTBM. MTBM is most responsive to shifts from

objective to threshold levels of break rate. The aircraft availability metric however, is relatively unchanged by variations in break rates. These relationships show that although aircraft breaks make up the majority down time events, the breaks are fixed fast enough to have minimal impact on aircraft availability while the scheduled maintenance actions have significant impact on aircraft availability.

Most notable from the results in Table 3, is the increase in the average number of required daily aircraft sorties per scheduled aircraft. With a reduced fleet size, the available aircraft must assume additional demand to complete the same load of work. At the threshold 64.7% availability level, a fleet of 53 aircraft will only have 25 aircraft on the flying schedule on a given day. The result is an average 22.39% increase in number of daily sorties each scheduled aircraft will have to complete.

Table 4. Attribute Trade Space with 70% Mission Capable Minimum

53 Acft, 7 GBTS, 141 MTBSM, 980 SMx Time							
Input				Results			
Break Rate	Fix Rate	Turn Time	GBTS -Ao	% Acft- Ao	MTBM	# Sorties/ Scheduled Acft/ Day	# Sorties/ Ao GBTS/ Day
T	T	T	T	69.93	13.36	2.27	2.83
T	T	T	O	69.95	13.36	2.27	2.52
T	T	O	T	70	13.39	2.27	2.83
T	T	O	O	70.02	13.42	2.27	2.52
T	O	T	T	70.14	13.43	2.27	2.84
T	O	O	T	70.03	13.40	2.29	2.84
T	O	T	O	69.94	13.42	2.29	2.54
T	O	O	O	70.13	13.42	2.28	2.52
O	T	T	T	70.18	15.10	2.27	2.84
O	T	T	O	70.17	15.13	2.28	2.53
O	T	O	T	70.14	15.13	2.28	2.84
O	T	O	O	70.36	15.10	2.26	2.51
O	O	T	T	70.24	15.07	2.27	2.83
O	O	T	O	70.47	15.13	2.25	2.51
O	O	O	T	70.54	15.12	2.25	2.82
O	O	O	O	70.43	15.1	2.26	2.52
95% Confidence Intervals				±0.2	±0.12	±0.02	±0.02
T= Threshold, O= Objective, MTBSM=Mean Time Between Scheduled Maintenance SMx Time= Mean Scheduled Mx Time							

Table 5. Attribute Trade Space with 80% Mission Capable Minimum

53 Acft, 7 GBTS, 141 MTBSM, 630 SMx Time							
Input				Results			
Break Rate	Fix Rate	Turn Time	GBTS -Ao	% Acft- Ao	MTBM	# Sorties/ Scheduled Acft/ Day	# Sorties/ Ao GBTS/ Day
T	T	T	T	80	13.44	2.00	2.84
T	T	T	O	80.07	13.41	2.00	2.51
T	T	O	T	79.96	13.41	2.00	2.84
T	T	O	O	80.01	13.41	2.00	2.52
T	O	T	T	80.1	13.38	2.00	2.85
T	O	O	T	80.18	13.39	2.00	2.83
T	O	T	O	80.06	13.43	2.00	2.53
T	O	O	O	80.19	13.42	2.00	2.52
O	T	T	T	80.21	15.09	2.00	2.84
O	T	T	O	80.25	15.13	2.00	2.52
O	T	O	T	80.2	15.11	2.00	2.84
O	T	O	O	80.22	15.10	2.00	2.53
O	O	T	T	80.27	15.17	2.00	2.85
O	O	T	O	80.45	15.10	2.00	2.51
O	O	O	T	80.37	15.04	2.00	2.83
O	O	O	O	80.3	15.11	2.00	2.54
95% Confidence Intervals				±0.15	±0.11	±0.02	±0.02
T= Threshold, O= Objective, MTBSM=Mean Time Between Scheduled Maintenance SMx Time= Mean Scheduled Mx Time							

Table 4 and Table 5 above support the same conclusions as Table 3. The availability of aircraft and the daily strain on scheduled resources does not significantly vary within the trade space of the measured performance levels when the scheduled maintenance plan is constant. The results again highlight that, at threshold levels of aircraft break rate, the threshold level of MTBM is not realistically obtainable. At objective levels of aircraft break rate, the objective level of MTBM is impossible to

reach. The scheduled maintenance plan utilized in these scenarios produce an average

MTBM of 15.11 flying hours. If no scheduled maintenance actions occurred, the average

would still only be 15.71 hours. With a fleet of 53 aircraft, the availability of resources

greatly depends on the scheduled maintenance plan.

When the scheduled maintenance plan adjusts to increase the fleet mission

capable rate, more aircraft are generated for scheduled sorties. With a mission capable

rate of 70%, a fleet of 53 aircraft would have 28 aircraft available for training. Each

scheduled aircraft executes an average of 12.94% more sorties than the current fleet of 65

aircraft. When the fleet mission capable rate increases to 80%, there are once again 31

aircraft available for sorties and the daily sorties are 0.5% lower than the current fleet.

The minimal decrease in sorties per aircraft noted in Table 5 is especially noteworthy

because it validates the T-X Utilization Rate Model.   The T-X Utilization Rate Model

was previously developed by the Air Force to determine the projected fleet size of 350

aircraft (Michalec, 2013). At a fleet mission capable rate of 80 percent, 53 aircraft could

do the same work as the current 65 without requiring a significant change in workload.

The data in tables three through five support the current plan to procure 350

replacement aircraft. Even though the proposed fleet is less than 80 percent the size of

the current fleet, it would still be able to maintain student pilot throughput.

Minimizing Resources

The next phase of this study explores the minimum quantities of aircraft and

GBTSs required to maintain on-time student pilot throughput. The model ran the

simulation multiple times with incrementally lower numbers of resources until on-time

student throughput dropped below 120 students. The table displays scenarios with the lowest number of resources that can still support 120-student throughput. Test scenarios included the extreme objective and threshold levels at the three mission capable rates described by tables three through five above. The results are listed in Table 6 below.

Table 6. Minimize Resources

Input		Results					
Break Rate, Fix Rate, Turn Time, GBTS -Ao	% Ao w/53 Acft	# Acft	# G B T S	% Acft-Ao	# MC Acft on Fly Schedule	# Sorties/ Scheduled Acft/ Day	# Sorties/ Ao GBTS/ Day
T	64.68	38	7	50.06 ±0.36	14.27 ±0.1	4.47 ±0.06	2.85 ±0.02
O	64.68	35	8	46.82 ±0.33	12.29 ±0.09	5.16 ±0.07	2.20 ±0.01
T	69.93	34	10	52.53 ±0.29	13.39 ±0.07	4.74 ±0.05	1.99 ±0.01
O	69.93	32	7	50.35 ±0.31	12.08 ±0.08	5.27 ±0.06	2.52 ±0.02
T	80.00	30	7	64.27 ±0.27	14.46 ±0.06	4.37 ±0.05	2.83 ±0.02
O	80.00	28	7	62.66 ±0.32	13.16 ±0.07	4.82 ±0.06	2.52 ±0.02
T= Threshold level O=Objective level						95% Confidence Intervals	

The data in Table 6 indicates that although the previous tests did not show significant variability when fleet size is constant, the delta between threshold and objective levels has significant impact on potential fleet size. At first look, it appears that dozens of aircraft could be cut without affecting the Air Force's ability to maintain the same graduate throughput. The number of sorties each aircraft would have to fly,

however, indicates that these levels are not feasible. Each aircraft on the flying schedule would have to fly at least four sorties a day and in some of the scenarios more than five. There are only enough hours in the day for an aircraft to fly five complete sorties. This means that every mission capable aircraft would have to be on the flying schedule every day in order to achieve the mission. In accordance with current maintenance practices, and as stated earlier in this study, 25% of the mission capable aircraft are not placed on a given day's flying schedule. This set of reserved aircraft ensures that the breaks that occur today do not adversely affect the follow days' schedules.

The data also shows that with a given scheduled maintenance plan, the mission capable rate drops when the fleet shrinks. This insight is often forgotten, as it is sometimes assumed that mission capable rates are scalable inputs dependent on individual aircraft rather than flying hours or number of sorties flown.

Addition analysis helped maintain realistic flying schedules as well as hold 25% of the mission capable aircraft in reserve for the following day. To understand the minimum number of aircraft, one must understand the minimum number of scheduled aircraft separate from reserved or broken aircraft in the fleet. To do this, the model ran objective and threshold scenarios that excluded scheduled maintenance. Aircraft break rates were still factored in because breaks happen during the day and reduce the available number of scheduled aircraft. To exclude nonscheduled maintenance assumes that broken aircraft are replaced that same day by reserved aircraft. No consideration is given to such replacement since it is not a desired plan of action. The result are shown below in Table 7.

Table 7. Minimized Scheduled Resources

Input		Results						
Break Rate, Fix Rate, Turn Time, GBTS -Ao	% Ao w/53 Acft	# Acft	# G B T S	% Acft-Ao	# MC Acft on Fly Schedule	# Sorties/ Scheduled Acft/ Day	# Sorties/ Ao GBTS/ Day
T	--	20	7	94.33 ±0.09	20	3.36 ±0.03	2.84 ±0.02
O	--	17	7	94.46 ±0.08	17	3.64 ±0.03	2.53 ±0.02
T= Threshold level O=Objective level					95% Confidence Intervals		

The data in Table 7 shows the minimum number of exclusively scheduled aircraft can support the syllabus flow of students. Unlike the scenarios in Table 6, these two scenarios simulate a situation where reserved aircraft cannot fly in the model. The number of daily sorties each aircraft flies are still high, but the scenarios are feasible.

Hypothesis testing validated that the combinations of aircraft and GBTS in Table 7 are statistically significant. Figure 8 below depicts the results of testing the null hypothesis that the average student throughput equals 120 students per year. With an alpha value of 0.05, the tests fail to reject the null hypothesis with the combinations listed in Table 7. Figure 8 shows that if the number of aircraft are reduced, from Thresh20 to Thresh19 and from Obj17 to Obj16, our results reject the null hypotheses. The data shows that with 19 aircraft in a threshold scenario, or 16 aircraft in an objective scenario, the goal of 120 annual pilot graduates is not sustainable at the 95% confidence level. A similar evaluation applied to reducing GBTS also verified the results of Table 7 and indicated that less than seven GBTS cannot support required annual student throughput.
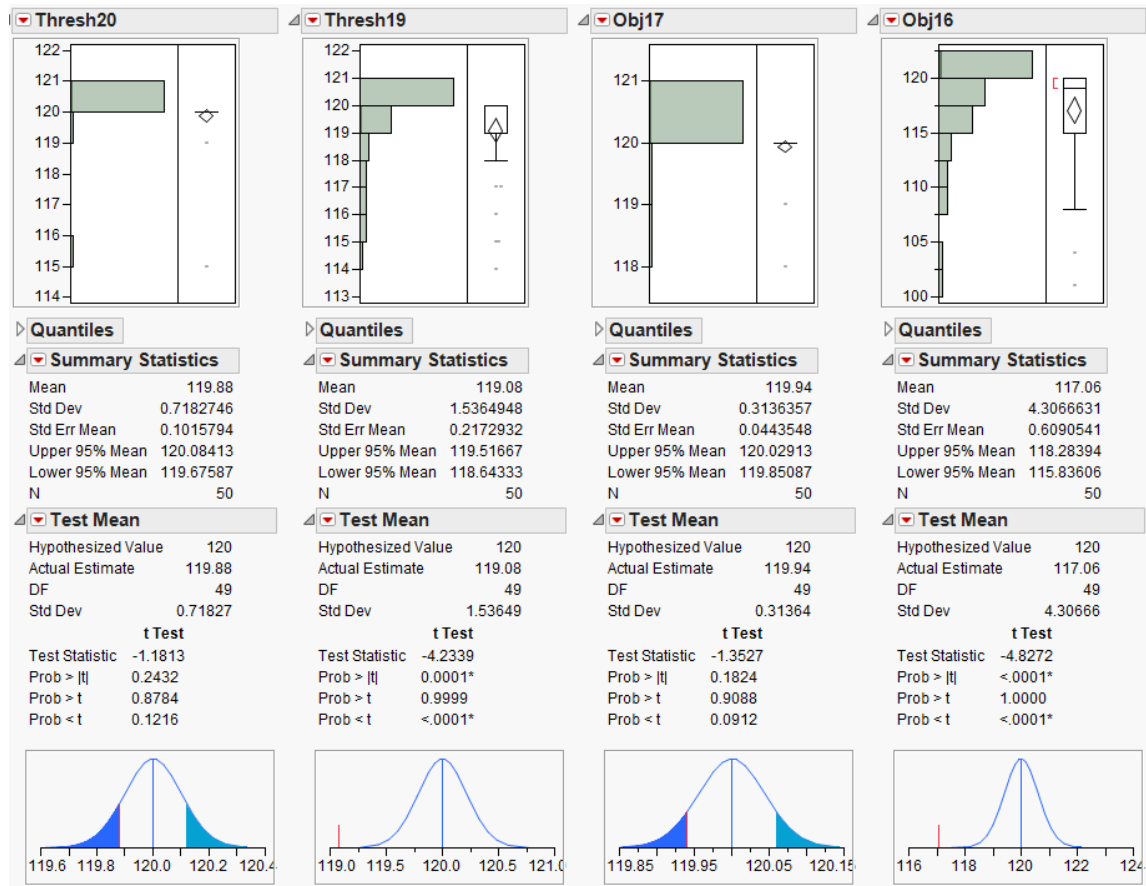
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Figure 8. Statistical Significance of Minimized Scheduled Resources

Using the information from Table 7, the model reevaluates the scenarios given in Table 6. The results are subject to the added constraints that objective scenarios cannot have any fewer than 17 aircraft scheduled and threshold scenarios cannot have any fewer than 20 aircraft scheduled. Table 8 below gives the results of the reevaluated minimum resources.

Hypothesis testing for Table 8 results use the null hypothesis of number of scheduled aircraft equals 17 or 20 for objective and threshold scenarios respectively. The results shown in Figure 9 confirm Table 8 scenarios are statistically significant, at $\alpha =$ 0.05, and meet annual student throughput and scheduled resource constraints.

Table 8. Minimized Fleet Scenarios

| Input		Results					
Break Rate, Fix Rate, Turn Time, GBTS -Ao	% Ao w/53 Acft	# Acft	# G B T S	% Acft-Ao	Minimum # MC Acft on Fly Schedule	# Sorties/ Scheduled Acft/ Day	# Sorties/ Ao GBTS/ Day
T	64.68	46	7	59.33 ±0.26	20	3.16 ±0.02	2.84 ±0.02
O	64.68	42	7	55.93 ±0.28	17	3.73 ±0.02	2.52 ±0.02
T	69.93	43	7	62.7 ±0.28	20	3.18 ±0.02	2.85 ±0.02
O	69.93	39	7	59.65 ±0.24	17	3.73 ±0.02	2.52 ±0.01
T	80.00	38	7	72.16 ±0.16	20	3.15 ±0.02	2.82 ±0.01
O	80.00	33	7	68.6 ±0.2	17	3.71 ±0.02	2.51 ±0.02
T= Threshold level O=Objective level					95% Confidence Intervals		
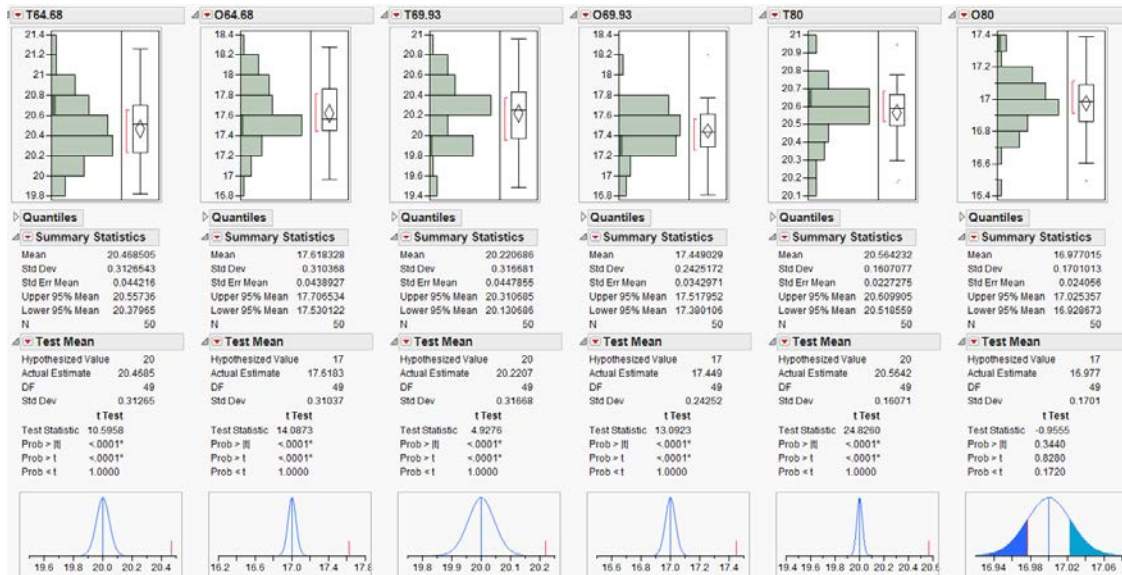
Figure 9. Statistical Significance of Minimized Fleet Scenarios

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The data from Table 8 gives a practical look at the minimum number of aircraft and GBTSs required to support the current syllabus with consideration to family of system attributes. Even though these fleet sizes are technically possible, they are not necessarily desirable. Decision makers can see from the number of daily sorties data that reduced fleet sizes require more aircraft turns than current operations usually support. In order to implement the fleet scenarios in Table 8, scheduled aircraft would have to fly 57% to 86% more than they currently do with a fleet of 65 aircraft.

V. Conclusions and Recommendations

Conclusions of Research

The study demonstrates that an analysis of aircraft FoS attributes in conjunction with student pilot syllabus requirements identifies potential procurement savings for the Air Force. This study supports the current plan to purchase 350 aircraft. The study also suggests that a different fleet size may be cheaper and just as effective. If a proposed trainer FoS performs above threshold performance levels, it may be more economical to purchase fewer of those aircraft. Likewise, it may be more economical to purchase more aircraft that are less capable but sufficient. The model developed in this study allows decision makers to determine the right size of the fleet based on proposed options for the T-X FoS and pilot training throughput requirements. After pilot training syllabi are updated to include bridge course requirements, the model in this study can be update to provide a better estimate of fleet requirements.

Significance of Research

This research combined previous studies that focused on student throughput and aircraft maintenance modeling into a single integrated model. With a combination of both elements, the model provides decision makers with a mission oriented approach to requirements planning. In the case of Air Force pilot student training, the mission is to graduate quality students. The mission is not just to move students through the system as fast as possible nor is it to ensure that aircraft generations reach a certain number. The combined look provided additional insight into the minimum number of resources required to complete the mission.

With mission accomplishment as the key goal, this study showed that aircraft availability rates could descend much lower than current thresholds. This suggests that although Ao metrics can be useful for improvement goals or measures of efficiency, they are not a good measure of mission effectiveness in a training environment. The Ao should not be discounted, but it should also not be used as a single point of evaluation.

This study also highlighted issues with MTBM, Break Rate, and Fix Rate criteria. One or all of these criteria need to be relaxed in order for the threshold level of each to be concurrently feasible with a realistic scheduled maintenance plan. This insight is beneficial not only to improve the metrics themselves, but also to highlight a potential problem with procurement requirements. The scheduled maintenance plan determines the vast majority of the Ao metric. The Ao metric is evaluated with only 20,000 fleet hours, a value that the fleet will hit after only a few months. With these circumstances, there is a risk that vendors will forego some scheduled maintenance requirements in the short run to improve the Ao metric. This could result in aircraft that require more maintenance in the long run and dramatically lower operational availability after 20,000 fleet hours have been flown. It may be beneficial for the Air Force to lengthen the fleet hours to encompass a year or two of fleet hours in order to capture all scheduled maintenance requirements.

In addition to providing a tool to right size a potential family of systems, the tool can also help decision makers educate others on the impact of reducing fleet structures. If the fleet size is reduced after a contract has already been awarded to a vendor, this tool will show what the Air Force can expect from the future fleet's performance. This tool shows that arbitrarily shrinking a fleet size after maintenance requirements have been set

significantly impacts the operational ability of aircraft. Mission capable rates are based on fleets, not individual aircraft. The tool helps to highlight this truth by showing the decrease in availability and the increase in the number of sorties each remaining aircraft will assume in order to maintain the same level of service.

Recommendations for Future Research

This study provided an introduction between combining student flow with aircraft availability models. Both sides of the issue could be further developed to generate more insights. Research could be expanded to include constraints on available number of instructors as well as inclusion of multilevel maintenance requirements. Any further development of the model must continue to focus on key aspects to keep analysis relatively simple.

Another area of future research could be a cost analysis of the decided upon fleet size. Potential savings are already identified by reducing resources, but the model does not address the costs associated with those savings. Cost should be evaluated specifically in additional maintenance requirements from higher rates of aircraft turns per day, as well as manpower requirements to support a multiturn flying schedule.

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14. ABSTRACT

This research develops a tool to aid Air Force decision makers in the acquisition of a new trainer aircraft family of systems. The study utilizes discrete event simulation to model the effects a prospective aircraft family of systems has on the flow of student pilots through training processes. Previous research has produced models for student throughput or aircraft availability, this research focuses on the intersection of both. Analysis of results provides insights into the quantity of resources required at the differing levels of performance to sustain a desired throughput of pilot graduates.

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